Available online at www.sciencedirect.com
SCIENCE DIRECT®
Renewable and Sustainable Energy Reviews
10 (2006) 269–279
RENEWABLE & SUSTAINABLE ENERGY REVIEWS
www.elsevier.com/locate/rser

Evaluation of alternative fuels for residential heating in Turkey using analytic network process (ANP) with group decision-making

Şenol Erdoğmuş[a], Haydar Aras[b,*], Eylem Koç[a]

[a]Statistics Department, Science and Art Faculty, Osmangazi University, 26480 Bati Meselik Eskisehir, Turkey
[b]Department of Mechanical Engineering, Engineering and Architecture Faculty, Osmangazi University, 26480 Bati Meselik Eskisehir, Turkey

Received 13 August 2004; accepted 17 September 2004

Abstract

Energy policies require cheap and continuous energy which is needed in Turkey for further development. Implementation of a successful energy policy requires political and economical institutions to take responsibility and to adopt adapt to changes easily. Energy policy generally consists of institutional structure, in which decisions related to technology, economy and energy are made, and also consists of supply–demand management in short term and planning in long term. Energy demand is closely related to social and economic structure of a society. In the long term development of energy demand, developmental structure of society (economic growth, life style, socio-economic factors), technological development and energy prices play important roles as determining factors. In this study, evaluation of most suitable fuel which can be used for residential heating was made using ANP with group decision-making.

Keywords: Fuel; Analytic network process; Natural gas

Contents

* Corresponding author. Tel.: +90 222 2393750; fax: +90 222 2393613.
E-mail address: haras@ogu.edu.tr (H. Aras).

1364-0321/$ - see front matter
doi:10.1016/j.rser.2004.09.003

1. Introduction

Turkey's energy production and consumption figures along with its fast developing and growing economy have grown rapidly in recent years. It is seen that mainly state institutions produce energy and that after transferring to planning period, state invested a lot in energy sector. The deficit in energy kinds, where production cannot meet demand, is met via import. Turkey is a country where local energy resources are limited and consumption is met via import. Today, it is expected by Ministry of Energy and Natural Resources that the imported energy share, 65%, will be 73% in 2010 and 78% in 2020. In this study, ANP is selected to solve the fuel selection problem. There are three reasons to use ANP. The first is ANP has a systematic approach to set priorities and trade-off among goals and criteria [1]. ANP uses a ratio scale by human judgments instead of arbitrary scales [2,3]. The second is ANP can measure all tangible and intangible criteria in the model [4–6]. The third is ANP is a relatively simple, intuitive approach that can be accepted by managers and other decision-makers [7,8]. Because of these reasons, we prefered ANP to other Operation Research/Management Science techniques to solve the problem.

The analytic hierarchy process (AHP) was first introduced by Saaty [4]. AHP is a well-known technique that decomposes a decision problem into several levels in such a way that they form a hierarchy. The AHP model assumes a uni-directional hierarchical relationship among decision level [9]. In AHP, the top element of the hierarchy is the overall goal for the decision model. The hierarchy decomposes from the general to a more specific attribute until a level of manageable decision criteria is met. AHP is conceptually easy to use, but it is divisionally robust so that it can handle the complexities of real-word problems [10]. Since the introduction of AHP in 1976, it is widely used in different decision-making process, such as measuring performance [11], policy development in the energy market [12], macroeconomic forecasting [13], setting priorities for objectives [14–19], evaluation of resources [20], filling systems [21], production cycles [22], banks [23], software [24], suppliers [25], electric power plants [26], fuel systems [27], crop production technologies [28], agricultural activities [28], reliability [29], and location [30–35] by academics and practitioners. In reality, AHP is a comprehensive framework which is designed to model the real world decision problems when we make multi-objective, multi-criterion and multi-actor decisions for any number of alternatives. An advantage of the AHP over other MCDM is that AHP is designed to incorporate tangible as well as intangible criteria especially where the subjective judgments of different individuals constitute an important part of the decision process [25,36]. The ANP is a general form of AHP and does not require this strictly hierarchical structure and

therefore allows for more complex interrelationships among the decision levels and attributes [37–39]. ANP incorporates dependencies and feedback using a multilevel (or hierarchical) decision network is well suited to modeling dependence (or interdependence) relations among components, to represent and analyze interactions, and to synthesize their mutual effects by a single logical procedure [40,41]. In the literature, the application of ANP is not as common as the applications of AHP. But application fields of ANP are rapidly increasing [42–48].

The objective of this study is to solve the complex decision problem by using ANP with BOCR and multi-actors. This article is divided into five sections. In Section 1, we present a brief review of ANP and the problem we studied. In Section 2, proposed ANP model is presented and the components of the model and relationships among them are determined in detail. In Section 3, the data used in the model are explained. In Section 4, how the analyses were done is described and discussions of the result are given. In Section 5, the results which have been obtained from solution of the model are evaluated.

2. Proposed ANP model

Here, we attempt to develop an ANP model about the decision problem. Determining the criteria in the ANP model is based on the evaluation obtained from actors. In this process the actors called a meeting. Criterion suggestions that may be used in the model were taken from participants in the meeting. These criteria were evaluated, and designated criteria as results of this evaluation were used ANP model. The criteria which were used here could be adapted to solve similar decision problems. The network model about decision problem structured around connections between the elements of clusters and ANP model was developed. The developed ANP model is a coupling of two parts. The first include a control hierarchy or network of criteria and subcriteria that control the interactions. The second is a network of influences among the alternatives, actors and criteria clusters [2]. This network consists of four kinds of subnetworks: benefits, opportunities, costs and risks, each of which represents the relationship of its own clusters and elements. Control hierarchy which forms the first part of the model is shown in Fig. 1.

At the top of the control hierarchy, there exists the goal of the problem. The goal is to determine the best strategic decision, namely the best Fuel. During the meetings with the actors, it came out that benefit, opportunity, cost, and risk has not equal importance for them. In order to determine the weights of BOCR, four strategic criteria have been added to the model. These strategic criteria are Input for national economy, Input for environment, Productive heating and Evaluation of domestic resources. Each of these criteria can be thought as subgoals that the actors are willing to realize. As a result, hierarchical structure between strategic criteria and overall goal is shown in Fig. 1 as control hierarchy.

Second part of the model consists of the network of interactions among the clusters of the alternatives, the criteria, and the actors. Consequently, in the second

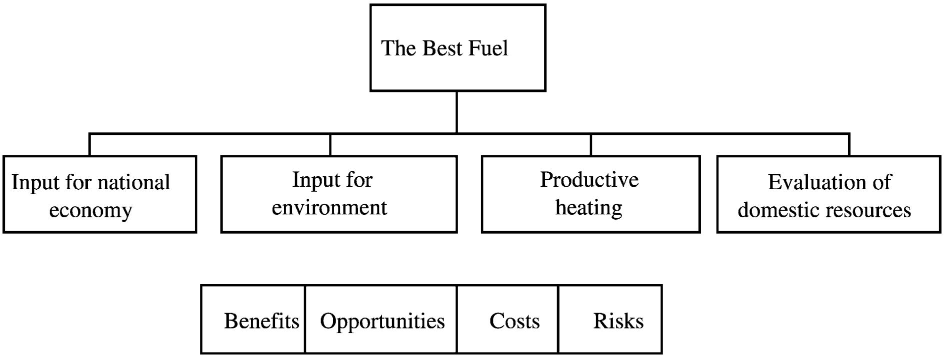

Fig. 1. Control hierarchy.

part, there are four subnetworks, namely benefits, opportunities, costs, and risks as presented in Figs. 2–5, respectively. Two types of connections between nodes contained in clusters in each subnetwork are represented in figures as one-way dependence and two-way dependence. If there is one-way dependences between

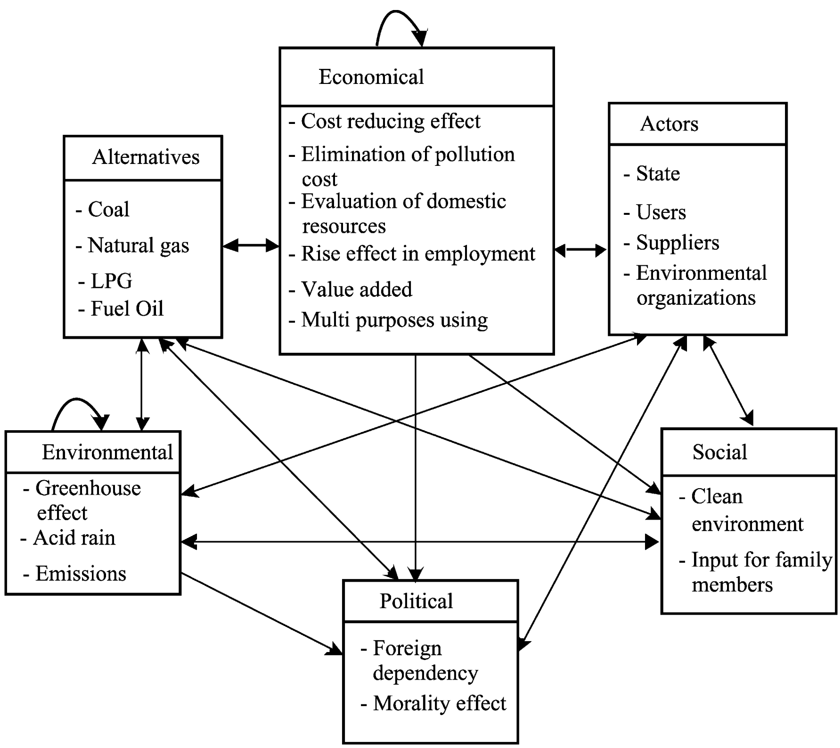

Fig. 2. Benefits subnetwork.

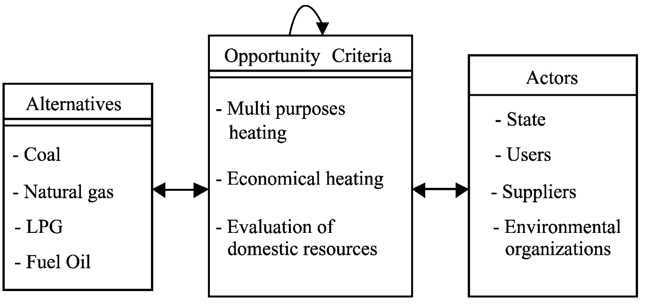

Fig. 3. Opportunities subnetwork.

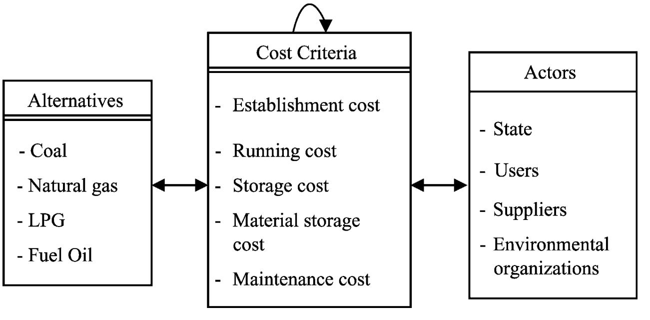

Fig. 4. Costs subnetwork.

the two clusters are represented with directed arrows. The two-way dependences are represented by bi-directed arrows.

The groups in actors' cluster in all subnetworks are not weighted among themselves. This means that decisions by clusters would have the same contribution to the final decisions.

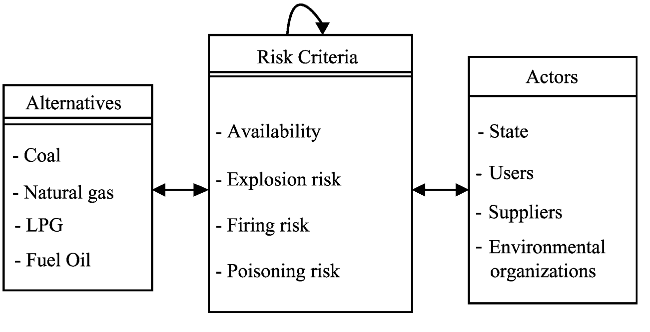

Fig. 5. Risks subnetwork.

Table 1
Pairwise comparison matrix

	INE	IE	PH	EDR
INE	–	1/5	1/2	1/2
IE	–	–	4	4
PH	–	–	–	1
EDR	–	–	–	–

3. Obtaining pairwise comparison matrices

After setting up the network model and required the connections, pairwise comparisons are performed. In order to do the pairwise comparisons, separate questionnaires are prepared for each actor group. The questions in these questionnaires are structured according to the connections that are related to each actor group. The questionnaires were prepared for the users, environmental organizations, state and suppliers.

While taking the judgment for each individual in each actor group, interviews were made separately each other, by using questionnaire technique. The scale that takes integer values between 1 and 9 were used in the technique recommended by Saaty [49]. The valuation scales in the pairwise comparisons are those, where 1 is equal importance, 3 is moderate importance, 5 is strong importance, 7 is very strong or demonstrated importance, and 9 is extreme importance. Even numbered values will fall in between importance levels.

Pairwise comparisons were based on upper level control criteria. In ANP model, weights of strategic criteria must be determined first. For this reason, the group which takes part in actors' cluster set made their pairwise comparisons about strategic criteria and notified their judgments according to overall goal. Consequently, four pairwise comparison matrices have been obtained for pairwise comparisons of strategic criteria. Geometric mean of judgment values which was obtained from all the pairwise comparisons was taken [49,50]. In the geometric mean, in the group of decision-makers, each perform the pairwise comparison process and the geometric mean of their evaluations is used to obtain the required pairwise comparison matrix [24,51]. As a result, pairwise comparison matrix obtained the geometric means about strategic criteria is given in Table 1.

Actor groups' judgments about pairwise comparisons related to connections were performed. In the result of these, there 92 pairwise comparison matrices obtained about judgments of actors for the whole model.

4. Analysis

Super Decisions software v.1.4.1 was used for the analysis. Total of 92 pairwise comparison matrices which were obtained in Section 3 were inputted into this program. The ANP analysis we performed involved four main steps.

In the first step of the analysis, consistency of the judgments is controlled. Especially, in the large scale decision problems, while doing pairwise comparisons, the respondents may misevaluate unconsciously. That is why it must be controlled that if pairwise comparison

Table 2
BOCR weights

	Input for national economy (0.092)	Productive heating (0.582)	Evaluation of domestic resources (0.163)	Input for environment (0.163)	Weights
Benefits	Very high	Very high	Very high	Very high	0.323
Opportunities	Very high	Very high	Very high	Very high	0.323
Costs	High	Very high	High	Medium	0.259
Risks	Very low	Medium	Low	Very low	0.095

matrices are consistent or not. If the matrix is inconsistent, the judgments of the respondents should be repeated until reliable judgments are obtained. The Super Decisions software calculates inconsistency ratio for every pairwise comparison matrix. In order a comparison matrix to be consistent, the inconsistency ratio must be less than 0.10 [52–54]. Since the inconsistency ratios of all pairwise comparisons matrices obtained in Section 3 were less than 0.1, all our pairwise comparison matrices were accepted as consistent.

Since benefits, opportunities, costs, and risks have not equal importance, BOCR weights will be determined in the second step of the analysis. It was mentioned in Section 2 that BOCR weights were based on strategic criteria. For this reason the actors were asked to evaluate BOCR bounding to strategic criteria by using five step scales (very high, high, medium, low, very low). The questions about evaluation of BOCR according to strategic criteria were asked to all groups at the same time and made them to be in consensus with their answers [24]. The groups in actor cluster were asked some questions like 'how much benefit there will be productive heating subgoal?' These evaluations are given in Table 2. Willingness to reach to strategic criteria, or subgoals, may not be always at the same level. In other words willingness to realize of a subgoal may be less than another subgoal. Consequently, the weights reflected mentioned willingness levels of strategic criteria computed by using Super Decisions software, and these weights were given in parenthesis under strategic criteria in Table 2. In the last column, BOCR weights were calculated based on the values of measurement levels, i.e. very high, 0.42; high, 0.26; medium, 0.16; low, 0.10; very low, 0.06 [49].

In the third step of the analysis, final relative weights of criteria in BOCR subnetworks were determined by using Super Decisions software (Table 3). These weights are based on pairwise comparison matrices that were obtained from the judgments of actor groups in Section 3.

Fourth step of the analysis is to determine relative importance values for the alternatives based on two formulas, the additive and the multiplicative. The additive and multiplicative formulas can be given as $bB+oO-cC-rR$ and $\{B^b O^o[(1/C)_{\text{Normalized}}]^c[(1/R)_{\text{Normalized}}]^r\}$, respectively, where *B, O, C* and *R* represent the synthesized results; whereas *b, o, c,* and *r* are BOCR rates [49,55,56]. Table 4 presents the synthesized results of each BOCR subnetwork in first four columns. Since the alternatives with the highest priorities in *C* and *R* columns are more costly and more risky, they are less preferred with respect to the others. To convert the priorities so that less preferred alternatives have lower values than more preferred ones, the reciprocals of each

Table 3
Final relative weights of subcriteria in BOCR subnetworks

		Criteria	Final relative weights		Criteria	Final relative weights
B	Economical	Cost reducing effect	0.15287	O	Multi-purposes heating	0.33776
		Elimination of pollution cost	0.30785		Economical heating	0.35909
		Evaluation of domestic resources	0.12145		Evaluation of domestic resources	0.30315
		Rise effect in employment	0.08887	C	Establishment cost	0.21789
		Value added	0.09817		Running cost	0.25151
		Multi-purposes using	0.23079		Storage cost	0.19331
	Social	Clean environment	0.85638		Material storage cost	0.19535
		Input for family members	0.14362		Maintenance cost	0.14194
	Political	Foreign dependency	0.16289	R	Availability	0.02919
		Morality effect	0.83711		Explosion risk	0.30330
	Environ-mental	Greenhouse effect	0.33334		Firing risk	0.33062
		Acid rain	0.33333		Poisoning risk	0.33689
		Emissions	0.33333			

alternative's priority are taken and presented in columns $1/C$ and $1/R$. Then, these reciprocals are normalized as shown in columns $N_{1/C}$ and $N_{1/R}$. The final relative importance values of the alternatives computed based on the additive and multiplicative formulas are given in the corresponding columns.

5. Discussions and conclusions

The focus of this paper is on the decision-making process itself, and not on the mathematical aspects of ANP. In this study, during the processes from defining the problem to interpretation of the results, there has been an interaction with the actors.

Table 4
Synthesized results for the alternatives in the control criteria network under the BOCR

Alterna-tives	B	O	C	R	$1/C$	$N_{1/C}$	$1/R$	$N_{1/R}$	Additive	Multipli-cative
Coal	0.108	0.270	0.095	0.095	10.5263	0.3014	9.4340	0.2681	0.087419	0.206497
Natural gas	0.732	0.543	0.730	0.730	1.3699	0.0392	1.3699	0.0389	**0.153405**	**0.235712**
LPG	0.089	0.108	0.080	0.080	12.5000	0.3579	12.1951	0.3465	0.035121	0.154581
Fuel oil	0.071	0.079	0.095	0.095	10.5263	0.3014	12.1951	0.3465	0.016055	0.124242
Total	1.000	1.000	1.000	1.000	34.9225	1.0000	35.1941	1.00000		

The consistency of the judgments is very important in ANP as it is in all the scientific research. In this study, in general all actor groups are very consistent with their judgments. In fact, our study reported very low inconsistency ratios of 0.00–0.0992, which are better than the recommended 10% acceptable margin.

In Table 2, the weights of BOCR were given. According to these results, approximate weights of BOCR which was obtained from the results of the calculations are 0.323, 0.323, 0.259 and 0.095, respectively.

Weights of BOCR criteria were given in Table 3. When this table was examined, one can see that the most important economical, social, political and environmental benefit criterion is *elimination of pollution cost*, *clean environment*, *morality effect* and *greenhouse effect*, respectively. The most important opportunity criterion is *economical heating*, the most important cost criterion is *running cost*, and the most important risk criterion is *poisoning risk*.

The final importance values about alternative fuels were given in Table 4. When we examine the results by using additive formula, we can see that the highest importance value alternative is *natural gas*. In other words, at the results of the analysis by using additive formula, *natural gas* is determined as the best alternative. Besides this, When we examine the results by using multiplicative formula we can see that the highest importance value alternative is *natural gas* again. So, since the alternative *natural gas* has the highest value according to both approach, it is proposed to use *natural gas* fuel system in place of the current coal system most commonly used in Turkey.

References

[1] Mishra S, Deshmukh SG, Vrat P. Matching of technological forecasting technique to a technology. Technol Forecast Soc Change 2002;69:1–27.

[2] Saaty TL. Fundamentals of the analytic network process. Kobe Japan: ISAHP; August 12–14 1999.

[3] Kim K, Park K, Seo S. A matrix approach for telecommunications technology selection. Comput Ind Eng 1997;33(3/4):833–6.

[4] Saaty TL. Fundamentals of decision making and priority theory with the analytic hierarchy process. AHP series, vol. VI. RWS Publications; 2000. 478 pp.

[5] Lee JW, Kim SH. Using analytic network process and goal programming for interdependent information system project selection. Comput Oper Res 2000;27:367–82.

[6] Momoh JA, Zhu JZ. Application of AHP/ANP to unit commitment in the deregulated power industry. IEEE 1998;817–22.

[7] Meade LM, Presley A. R&D project selection using the analytic network process. IEEE Trans Eng Manage 2002;49(1):59–66.

[8] Presley A, Meade L. Strategic alignment and IT investment selection using the analytic network process, (ACIS'99), Milwaukee, WI; 1999. p. 411–3 (Downloadable from website http://aisel.isworld.org/article.asp?Subject_ID=25&Publication_ID=2).

[9] Meade LM. A methodology for the formulation of agile critical business processes. Presented to the Faculty of the Graduate School of The University of Texas at Arlington in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy. The University of Texas at Arlington; May 1997.

[10] Salo AA, Hamalainen RP. On the measurement of preferences in the analytic hierarchy process. J Multi-Criteria Decision Anal 1997;6:309–19.

[11] Frei FX, Harker PT. Measuring aggregate process performance using AHP. Working Paper, vol. 7. The Wharton Financial Instutions Center, The Wharton School, University of Pennsylvania, Philadelphia; 1998 p. 1–14.
[12] Chedid RB. Policy development for solar water heaters: the case of Lebanon. Energy Convers Manage 2002;43:77–86.
[13] Blair AR, Nachtmann R, Saaty TL, Whitaker R. Forecasting the resurgence of the US economy in : an expert judgement approach. Socio-Econ Plan Sci 2001;36:71–91.
[14] Kwak NK, Lee C. A multicriteria decision-making approach to university resource allocations and information infrastructure planning. Eur J Oper Res 1998;110:234–42.
[15] Schniederjans MJ, Wilson RL. Using the analytic hierarchy process and goal programming for information system project selection. Inf Manage 1991;20:333–42.
[16] Kwak NK, Lee CW. Business process reengineering for health-care system using multicriteria mathematical programming. Eur J Oper Res 2002;140:447–58.
[17] Radash DK, Kwak NK. An integrated mathematical programming model for offset planning. Comput Oper Res 1998;25(12):1069–83.
[18] Ramanathan R. A note on the use of goal programming for the multiplicative AHP. J Multi-Criteria Decision Anal 1997;6:296–307.
[19] Lee CW, Kwak NK. Information resource planning for a health-care system using an AHP-based goal programming method. J Oper Res Soc 1999;50:1191–8.
[20] Jaber JO, Mohsen MS. Evaluation of non-conventional water resources supply in Jordan. Desalination 2001; 136:83–92.
[21] Boucher TO, Luxhoj JT, Descovich T, Litman N. Multicriteria evaluation of automated filling systems: a case study. J Manufact Syst 1993;12(5):357–78.
[22] Weck M, Klocke F, Schell H, Rüenauver E. Evaluating alternative production cycles using the extended fuzzy AHP method. Eur J Oper Res 1997;100:351–66.
[23] Ta HP, Har KY. A study of bank selection decisions in Singapore using the analytical hierarchy process. Int J Bank Marketing 2000;18/4:170–80.
[24] Lai VS, Wong BK, Cheung W. Group decision making in a multiple criteria environment: a case using the AHP in software selection. Eur J Oper Res 2002;137:134–44.
[25] Mohanty RP, Deshmukh SG. Use of analytic hierarchic process for evaluating sources of supply. Int J Phys Distribution Logist Manage 1993;23(3):22–8.
[26] Akash BA, Mamlook R, Mohsen MS. Multi-criteria of electric power plants using analytical hierarchy process. Electric Power Syst Res 1999;52:29–35.
[27] Poh KL, Ang BW. Transportation fuels and policy for Singapore: an AHP planning approach. Comput Ind Eng 1999;37:507–25.
[28] Alphonce CB. Application of the analytic hierarchy process in agriculture in developing countries. Agric Syst 1997;53:97–112.
[29] Fahmy HMA. Reliability evaluation in distributed computing environments using the AHP. Comput Networks 2001;36:597–615.
[30] Tzeng G, Teng M, Chen J, Opricovic S. Multicriteria selection for a restaurant location in Taipei. Int J Hospitality Manage 2002;21:171–87.
[31] Kim PO, Lee KJ, Lee BW. Selection of an optimal nuclear fuel cycle scenario by goal programming and the analytic hierarchy process. Ann Nucl Energy 1999;26:449–60.
[32] Kengpol A. The decision support system to select the investment in a new distribution centre using the analytic hierarchy process, a capital investment model and a transportation model. Journal KMITNB 2002; 12(2):31–7.
[33] Atthirawong W, MacCarthy B. An application of the analytical hierarchy process to international location decision-making. In: Seventh Cambridge research symposium on international manufacturing. Centre for International Manufacturing, Cambridge University; 2002.
[34] Kuo RJ, Chi SC, Kao SS. A decision support system for selecting convenience store location through integration of fuzzy AHP and artificial neural network. Comput Ind 2002;47:199–214.
[35] Yang J, Lee H. An AHP decision model for facility location selection. Facilities 1997;15(9/10):241–54.

[36] Iwasaki S, Tone K. A search model with subjective judgments: auditing of incorrect tax declarations. Omega Int J Manage Sci 1998;26(2):249–61.
[37] Raisinghani M. A balanced analytic approach to strategic electronic commerce decisions: a framework of the evaluation method. In: Van Grembergen W, editor. Information technology evaluation methods and management. Hershey, PA: Idea Group Publishing; 2001. p. 185–97.
[38] Kameya N, Miyagi H, Taira N, Yamashita K. Multiple-criteria decision-making using sectional supermatrix. Proceedings of international technology conference on circuits/systems, computers and communications; 2002. p. 838–40.
[39] Meade L. Strategic analysis of logistics and supply chain management systems using the analytical network process. Transp Res Part E—Logist Transp Rev 1998;34(3):201–15.
[40] Kahalekai L, Phillips L. Using analytic network process (ANP) methodology for the analysis, evaluation, and recommendation of courses of action (COA) based on economic, political, sociological, cultural, and psychological factors critical to operations other than war (OOTW). Presented at the Huntsville Simulation Conference, Huntsville-Alabama; 2002.
[41] Sarkis J, Sundarraj RP. Hub location at digital equipmant corporation: a comprehensive analysis of qualitative and quantitative factors. Eur J Oper Res 2002;137:336–47.
[42] Sarkis J. A strategic decision framework for green supply chain management. J Cleaner Prod 2003;11: 297–409.
[43] Momoh JA, Zhu J. Optimal generation scheduling based on AHP/ANP. IEEE Trans Syst Man Cybern—Part B: Cybern 2003;33(3).
[44] Partovi FY, Corredoira RA. Quality function deployment for the good of soccer. Eur J Oper Res 2002;137: 642–56.
[45] Agarwal A, Shankar R. Analyzing alternatives for improvement in supply chain performance. Work Study 2002;51(1):32–7.
[46] Hong S, Cho K. An application of ANP approach based on Porter's diamond framework. Conference of the Korean institute of industrial engineers, Korea University; 1998.
[47] Karsak EE, Sozer S, Alptekin SE. Product planning in quality function deployment using a combined analytic network process and goal programming approach. Comput Ind Eng 2002;44:171–90.
[48] Lee JW, Kim SH. An integrated approach for interdependent information system project selection. Int J Project Manage 2001;19:111–8.
[49] Saaty TL. The analytic network process. Pittsburgh: RWS Publications; 2001. 376 pp.
[50] Rossetti MD, Selandari F. Multi-objective analysis of hospital delivery systems. Comput Ind Eng 2001;41: 309–33.
[51] Duke JM, Aull-Hyde R. Identifying public preferences for land preservation using the analytic hierarchy process. Ecol Econ 2002;42:131–45.
[52] Soma K. How to involve stakeholders in fisheries management—a country case study in Trinidad and Tobago. Marine Policy 2003;27:47–58.
[53] Cox AM, Alwang J, Johnson TG. Local preferences for economic development outcomes: analytical hierarchy procedure. Growth Change 2000;31:341–66.
[54] Bodin L, Gass SI. On teaching the analytic hierarchy process. Comput Oper Res 2003;30(10):1487–97.
[55] Saaty TL, Ozdemir M. Negative priorities in the analytic hierarchy process. Math Comput Modell 2003; 37(9/10):1063–75.
[56] Saaty TL. Rank from comparisons and from ratings in the analytic hierarchy/network processes. Eur J Oper Res 2004 [in press].